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July 9, 1991

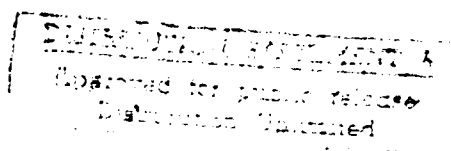
Defense Technical Information Center
Bldg. 5 Cameron Station
Alexandria, VA 22314

Dear Sirs:

I enclose the final report on my ONR contract
N00014-88-K-0557. The grant duration was August 1, 1988 -
September 31, 1989.

Sincerely,

Carl Gunter
Carl Gunter



**Best
Available
Copy**

ONR CONTRACT INFORMATION

Contract Title: *Type Theory and Programming Languages.*

Contract Number: N00014-88-K-0557

Scientific Officer: Ralph Wachter

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| ADDITIONAL INFORMATION | |
| NONSERIALIZED | |
| UNCLASSIFIED | |
| DATE 11-11-88 | |
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Summary of Research for Carl A. Gunter¹

Models of Polymorphism. In the last year I completed the publication of my joint work with Thierry Coquand (INRIA, France) and Glynn Winskel (Aarhus, Denmark) on mathematical models of polymorphism. We showed that a construction from algebraic geometry known as a *Grothendieck fibration* can be used to develop interesting new models of subtle programming type structures. The final article on this work will appear in **Information and Computation** sometime this year.

Expository Writing. As part of an on-going attempt to make the mathematical theory of semantic domains more accessible to mathematicians and engineers, my PhD advisor, Dana Scott (CMU, USA) and I have completed a chapter on the subject for the up-coming North-Holland **Handbook of Mathematical Logic** which should appear sometime in 1989.

L-domains. The majority of my work concentrated on the study of a class of structures (called *coherent L-domains*) which I introduced in my PhD dissertation which have become a topic of interest in the semantics community. Achim Jung (Darmstadt, FDR) and I demonstrated a *universal domain* for this class and showed how concepts from first order model theory could be used to build canonical universal domains for various classes of spaces used for the semantics of programming languages. We presented our work at the Symposium on **Logic in Computer Science** this summer and a full journal article is being reviewed for publication in **Pure and Applied Algebra**.

Productivity! With Val Breazu-Tannen (Penn, CIS) and Peter Buneman (Penn, CIS) I wrote a popular (i.e. non-technical) paper on the potential impact of typed functional programming techniques on software engineering practice. The goal was to persuade a larger community of the practical significance of our mathematical results. Our paper was presented at the Symposium on **Productivity: Progress, Prospects and Payoff** in Washington this spring.

Powerdomains. I completed a paper on a logical characterization of a class of operators called *powerdomains* which are a continuing topic of study in programming semantics and database theory. This new characterization is intended to speed our understanding of the potential significance of powerdomains for research in artificial intelligence and databases where very similar concepts are viewed in interesting new ways. My paper was presented at the workshop on **Mathematical Foundations of Programming Semantics** in Boulder, Colorado this Spring and I have given several successful colloquium talks on it this summer. The paper is being reviewed for publication in **Theoretical Computer Science**. I expect to continue research on related topics this next year in conjunction with Peter Buneman and Susan Davidson (Penn, CIS) who are interested in database applications of powerdomains.

Models of Inheritance. Currently Val Breazu-Tannen, Andre Scedrov (Penn, Mathematics) and I are working out a new view of inheritance and type quantification based on the view that some advanced languages with inheritance concepts can be viewed as subtle syntactic sugarings for better understood languages such as the polymorphic lambda calculus. In this way we hope to

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provide the first models of new programming languages such as Quest which combine inheritance, impredicativity and type recursion in one language. The research seems quite promising and we intend to prepare a paper sometime this Fall.

Basic Research Directions. My central objective is to demonstrate that concepts from mathematical logic in general and semantics in particular can be used to improve computing practice. Currently, one of the most promising avenues for such achievement is through the development of new concepts in programming language type systems and it is on this that I plan to focus the majority of my attention. There is also some exciting promise of establishing an interesting relationship between concepts in *concurrency* and type theory. I hope to explore any new ideas in this area that arise. My PhD student, Vijay Gehlot, who is currently supported by the Office of Naval Research, will be doing research in this direction.

Planned Activities. I have been invited to write a chapter on the semantics of type disciplines for Oxford University Press's **Handbook of Logic in Computer Science**. This will be a substantial, advanced work which will survey the research in my area. I have received an invitation as a Visiting Scientist at Cornell University's Mathematics Institute for part of this November and I hope to exposit some of the ideas I have mentioned above in a series of lectures I will give there. I have invitations for colloquium talks at Stanford and SRI (Palo Alto) that I hope to give this December. I also hope to take advantage of several more local invitations (*eg.* ATT and Brown) and a couple of invitations in Ontario (Queens College and the University of Ottawa). I am especially looking forward to working with some of the guests who will be at Penn this year such as Thierry Coquand and Samson Abramsky (Imperial College, England) who will come for extended visits. Achim Jung has applied to the German NSF for me to have a Visiting Scientist position in Darmstadt sometime this year. Also I will serve on the program committee for the Conference on **Mathematical Foundations of Programming Semantics** which will take place this Spring in New Orleans.

List of Publications/Reports/Presentations

1. **Papers Published in Refereed Journals:** *Domain theoretic models of polymorphism. Information and Computation.* (Joint with Thierry Coquand and Glynn Winskel.)
2. **Technical reports:**
 - (a) *Domain theoretic models of polymorphism.* (Joint with Thierry Coquand and Glynn Winskel.) MS-CIS-88-38 LINC LAB 115. Also in: **Information and Computation.**
 - (b) *A logical characterization of powerdomains.* MS-CIS-88-31 LINC LAB 111. (Submitted to **Theoretical Computer Science.**)
 - (c) *Coherence and consistency in domains.* (Joint with Achim Jung.) MS-CIS-88-20 LINC LAB 106. (Submitted to **Journal of Pure and Applied Algebra.**)
3. **Presentations:**
 - (a) Invited.
 - *A logical characterization of powerdomains*, IBM, T. J. Watson Research Laboratory, U.S.A., July 1988
 - *A logical characterization of powerdomains*, Imperial College, London, England, July 1988
 - *Domain theoretic models of polymorphism*, University of Colorado at Boulder, U.S.A., January 1988
 - *Coherence and consistency in domains.* Carnegie-Mellon University, April 1988: **Workshop on Semantics of Lambda Calculus and Category Theory.**
 - *Domain theoretic models of polymorphism*, University of Canterbury, England, October 1987.
 - (b) Contributed.
 - *Coherence and consistency in domains.* **Logic in Computer Science**, edited by Y. Gurevich, IEEE Computer Society Press, Edinburgh, Scotland, July 1988. (Joint with Achim Jung.)
 - *Typed functional programming for the rapid development of reliable software. Productivity: Progress, Prospects and Payoff*, edited by J. E. Gaffney, Association for Computing Machinery, Gaithersburg, Maryland, USA, June 1988. (Joint with Peter Buneman and Val Breazu-Tannen.)
 - *A logical characterization of powerdomains*, **Workshop on Mathematical Foundations of Programming Language Semantics**, Boulder, Colorado, USA, May 1988.
4. **Books and sections thereof:** *Semantic domains. Handbook of Theoretical Computer Science*, edited by A. R. Meyer, M. Nivat, M. S. Paterson, and D. Perrin, North Holland. (Joint with Dana Scott.)

PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT

- Papers submitted to refereed journals (and not yet published): 2
- Papers published in refereed journals: 1
- Books (and sections thereof) submitted for publication: 0
- Books (and sections thereof) published: 1
- Patents filed: 0
- Patents granted: 0
- Invited presentations at topical or scientific/technical society conferences: 1
- Contributed presentations at topical or scientific/technical society conferences: 3
- Honors/Awards/Prizes: 0
- Technical reports published or non-refereed journal publications: 3
- Number of graduate students: 1
- Number of post docs: 0